Time-optimal motion planning in the presence of moving obstacles

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1 Introduction

Autonomous motion systems are becoming more and more popular in industry. Some examples are AGV's, fruit picking robots, welding robots, drones and autonomous cars. To drive these systems, one generally wants to compute the fastest or the most energy efficient motion trajectory to move the system from its current position to its destination while obeying input and state constraints and avoiding collision with obstacles in the environment. This motion trajectory is typically computed by solving an optimization problem. As autonomous systems often operate in environments with moving obstacles of which the motions are not fully known a priori, the trajectory needs to be updated in real time.

This abstract presents a method for calculating a time-optimal motion trajectory in the presence of moving obstacles. The method has two key aspects: (*i*) via a B-spline parametrization of the motion trajectory it is possible to make a trade-off between the complexity of the optimization problem and the optimality of the resulting trajectory; (*ii*) the properties of B-splines allow to transform all constraints to conservative constraints on the B-spline coefficients. This relaxation lowers the amount of constraints. These aspects lead to a small scale optimization problem that is suitable for real-time implementation [2].

The method has been tested extensively by numerical simulations. In addition, it has been validated in an experimental demo where a *KUKA youBot* moved time-optimally from one point to another while avoiding a moving obstacle.

2 Methodology

The time-optimal B-spline trajectory is determined by solving an optimization problem with the motion time as the *objective function*. The *optimization variables* are the motion time and the spline coefficients. Three types of constraints are considered: (*i*) *kinematic constraints*, limiting the speed and acceleration of the vehicle; (*ii*) *initial and final conditions*, imposing the vehicle's initial and final position, speed and acceleration; and (*iii*) *anti-collision constraints*, ensuring the vehicle avoids all obstacles in its environment. Currently, the anti-collision constraints can cope with ellipsoidal and rectangular vehicles and obstacles. For rectangular obstacles and/or vehicles, the constraints are based on the separating hyperplane theorem [1].

In order to deal with moving obstacles, a linear prediction of their future positions, based on the current position, orientation and speed, is added to the anti-collision constraints. To account for uncertainty in this prediction the proposed method re-optimizes the trajectory in each time step by using new initial conditions, and updated obstacle information and velocity estimation.

The developed method allows generating a time-optimal point-to-point trajectory to avoid elliptical, circular and rectangular obstacles with a circular or rectangular vehicle or robot. In future work, more general vehicle and obstacle shapes will be considered, as well as including the vehicle's dynamics.

3 Results

Figure 1 shows an optimal motion trajectory for moving a circular robot from the start point to the marked end point. When the dashed static circular obstacle is also considered the optimal trajectory changes to the dashed trajectory.

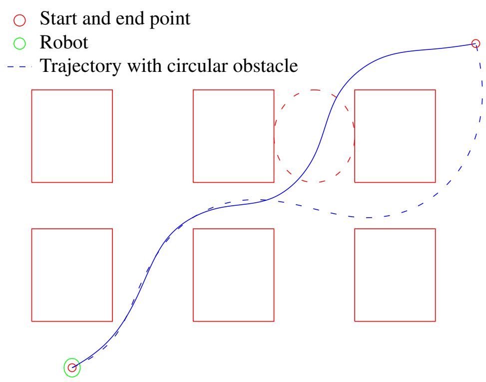

Figure 1: Circular robot moving through a warehouse

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